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Ice storm and fertilization effects on root starch, sap productivity and sweetness, diameter growth, and tap hole closure in sugar maple stands of eastern Ontario

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Summary

The effect of fertilizer was examined on 15 sugar maple stands in eastern Ontario managed for syrup production that sustained 7% to 72% ice-induced crown damage. Stands were divided into 4 plots that received the following fertilizer treatments: dolomitic lime – calcium (Ca) and magnesium (Mg), phosphorous (P) and potassium (K), and lime plus P+K treatments and no fertilizer in June 1999. The effects of crown damage level and fertilization on root starch, sap volume, sap sugar content, syrup production, and tap hole closure rate were examined during Phase I of this study, which ran from 1998 to 2001. During Phase II fall root starch content and stem diameter growth (fall of 2003), sap volume and sugar content, hourly block temperatures measured during the sap run (spring of 2004), and tap hole closure (fall of 2004) were examined and effects on syrup production calculated.

Fall root starch content, sap volume, and tap hole closure rate were not affected by crown damage level. Sugar content of sap was reduced in trees with moderate (26-50%) and severe (>50%) damage. Moderate damage also lowered syrup production per tap. Daily air temperature amplitudes were about 1°C greater in moderately and severely damaged stands compared to lightly (0-25%) damaged stands. Moderately and severely damaged trees also had less stem diameter growth in 1999, 2000, and 2001, but not in 2002 and 2003. The fertilizer and lime treatments had no significant effects. Results suggest that ice storm damage to crowns has significant effects on sap sweetness and syrup production capacity of sugar maple for up to 6 years.

Résumé

On a examiné les effets d'engrais sur 15 peuplements d'érables à sucre de l'Est de l'Ontario aménagés pour la production de sirop dont la cime avait subi entre 7 et 72 % de dommages causés par le verglas. Les peuplements ont été divisés en quatre parcelles ayant été traitées avec les engrais suivants en juin 1999 : chaux dolomitique – calcium (Ca) et magnésium (Mg), phosphore (P) et potassium (K), et chaux et traitements de P et de K. Une parcelle n'a reçu aucun engrais. Lors de la phase 1 de l'étude, qui a eu lieu de 1998 à 2001, on a étudié les effets des dommages causés aux cimes et de la fertilisation sur les réserves d'amidon des racines, le volume de sève, la teneur en sucre de la sève, la production de sirop et le taux de fermeture des entailles. Pendant la phase II, on a étudié la teneur en amidon des racines à l'automne et l'accroissement du diamètre de la tige (automne 2003), le volume de sève et sa teneur en sucre, la température des blocs toutes les heures pendant la coulée de sève (printemps 2004) et la fermeture des entailles (automne 2004) puis on a calculé la production de sirop. La teneur en amidon des racines à l'automne, le volume de sève et le taux de fermeture des entailles n'ont pas été affectés par les dommages subis par les cimes. La sève des arbres ayant subi des dommages moyens (entre 26 et 50 %) ou graves (plus de 50 %) avait une teneur en sucre plus faible. En outre, les arbres ayant subi des dommages moyens produisaient moins de sirop par entaille. L'amplitude quotidienne de la température de l'air parmi les peuplements ayant subi des dommages moyens ou graves était d'environ 1 °C supérieure à celle des peuplements ayant subi des dommages légers

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(entre 0 et 25 %). De plus, l'accroissement du diamètre de la tige des peuplements ayant subi des dommages moyens ou graves était inférieur en 1999, 2000 et 2001, mais non en 2002 et 2003. Les engrais et les traitements à la chaux n'ont pas eu d'effets majeurs. Les résultats obtenus laissent croire que les dommages causés aux cimes par la tempête de verglas ont eu des effets importants sur la teneur en sucre de la sève et la capacité de production de sirop des érables à sucre pendant une période pouvant atteindre six ans.

Introduction

The ice storm of January 5-10, 1998 was one of the worst weather disasters ever recorded in Canadian history (Milton and Bourque 1999) – unprecedented in its duration, severity, and area affected (Chapeskie 1999). At its peak, the ice storm covered about 604,000 km^2 of eastern Ontario (Hopkin et al. 2003), much of southwestern Quebec, and spread into Atlantic Canada and adjacent areas of northeastern United States. As a result of this storm, trees throughout eastern Ontario, including sugar maple in stands used for maple syrup production suffered extensive crown damage.

Critical research needs identified by Ontario maple syrup producers included the impact of crown damage on: (1) tree health as measured by fall root starch content, (2) the rates of mortality and recovery for damaged stands, and (3) maple syrup productivity as measured by sap volume and sweetness (Chapeskie and Nielsen 1998). In response, the Ontario ministries of Natural Resources and Agriculture, Food, and Rural Affairs, the Canadian Forest Service, and numerous university scientists initiated a collaborative multi-disciplinary research program to address these needs (Lautenschlager and Nielsen 1999). Subsequent literature reviews indicated that little was known about the impact of ice storm crown damage on sugar maple health and syrup productivity (Coons 1999, Van Dyke 1999).

As a result, a research project was initiated to investigate crown damage and fertilization effects on sap volume and sugar content, syrup production, root starch content, and tap hole closure rate from the first 3 years after the storm (1998-2001). Early results of this research (phase I) have been published (Noland 2003). The objective of Phase II of this project was to determine the longer-term effects of ice storm damage on sugar maple syrup productivity as well as whether fertilizer and lime treatments, applied to enhance crown recovery, ameliorated the damage.

Methods

Plot network

In 1998, 34 1-ha (2.47 acres) blocks were established throughout the heavily ice-damaged area of eastern Ontario in privately owned sugar bushes (Lautenschlager and Nielsen 1999). At time of establishment, each block was rated for ice damage by visually estimating the percentage of branches in each tree crown that were removed (Lautenschlager and Winters 2001). Each block was classified into a damage category based on the amount of crown affected by ice damage: light (0 - 25%), moderate (26%-50%), and severe (51% +). Each block was then divided into 4, 0.25-ha (0.62 acre) plots and treated with fertilizer at the following rates: (i) 2 tonnes (2,205 lbs.) of dolomitic lime ha^{-1}, (ii) 200 kgs (441 lbs.) of P and K ha^{-1}, (iii) lime plus P and K, or (iv) no nutritional additions (control) in June 1999. At the time of establishment, 6 focus trees per plot (24 per block) were chosen and marked to measure diameter growth, root starch, sap production, and tap hole closure rate, as well as the average block damage level. Six severely, 5 moderately, and 4 lightly damaged blocks were chosen for sap monitoring in Phase I of the study (Noland 2003). For phase II, 1 severe damage block was dropped and 1 light damage block was added to provide an equal number (5) of blocks for each damage level. At establishment, the following parameters were measured: tree damage, focus tree height and diameter at breast height (DBH), basal area (m^2 ha^{-1}), and root diameter of two roots sampled per tree for starch.

Root starch, stem, sap, and temperature sampling

Fall root starch samples were collected in November 2003 by taking (Wargo 1979) increment cores, 2 to 3 cm (0.8 to 1.2 inches) long, from 2 surface roots in each of 3 focus trees per treatment plot (12 trees per block) in the 15 sap blocks. Stem diameter changes were quantified using increment cores 2 to 3 cm (0.8 to 1.2 inches) long from the trunk at about 1.4 m (4.5 feet) above the ground from all 6 focus trees per treatment plot of the 15 blocks. Trees were tapped using standard 11.1 mm (7/16 inch) diameter spiles with a taphole 6.35 cm (2.5 inches) deep using conservative tapping guidelines: a maximum of 2 taps per tree (Chapeskie and Nielsen 1998). Sap was collected using a bucket system with drain tubes attached to spiles. Sap collections and root starch samples were taken from the same 3 focus trees per plot. Sap collections were made every other day while sap was running during the spring of 2004 (March 8 – April 20). Syrup

production was calculated by multiplying seasonal sugar content average times total seasonal sap volume using the rule of 84 (Walters 1982). Tap hole closure rate was measured in November 2004 as percent closure. Hourly air temperature recorders (Hobo, Hoskins Scientific) were installed at the centre of each of the 15 blocks at 1 m above the ground for the duration of the sap run.

Starch analysis

Starch was extracted using 1.5 ml of methanol: chloroform: water mixture (12:5:3 v:v:v) (Haissig and Dickson 1979), repeated 3 times on each 25 mg DM (freeze-dried mass) root tissue sample (ground with size 20 mesh). Root starch was analyzed using a Waters' HPLC system as described in Noland et al. (1997).

Statistical analyses

The experiment was established as a split-plot completely randomized block design. The main effect being investigated is crown damage level. The split plot for each block is the fertilizer treatments. Although set up as a completely randomized block design, this portion of the study was analyzed with each individual tree considered an independent sample unit. The response of each tree to the treatments, in terms of root starch, sap and syrup production, was independent of the other trees in the block. Relationships between each response variable (i.e., root starch, sap volume and sugar content, and calculated syrup production) and damage were examined using analysis of variance (ANOVA) in SigmaStat 3. Residuals were plotted and checked for normality and homogeneity of variance and when normality conditions were not met, nonparametric analysis was performed using Kruskal-Wallis ANOVA. In the case of significant categorical variables, a posteriori means testing was carried out using the Student-Newman-Keuls means test ($P \leq 0.05$) for normally distributed data and the nonparametric Dunn's mean test ($P \leq 0.05$) for nonnormally distributed data.

Results

The fall root starch levels, sap volume produced per tap, and fall tap hole closure rates in maple were not affected by ice storm damage levels (Table 1). In moderately or severely damaged trees, sap sweetness and diameter growth were significantly reduced (Figures 1 and 2). However, potential syrup production was only significantly lowered in moderately damaged trees. Diameter growth was not affected by damage level in 2002 and 2003, but was reduced by crown damage in 1999, 2000, and 2001. Tree height and branch number did vary significantly with damage level (Table 2). Severely damaged trees averaged over 1 m shorter and had about 6 less branches per tree than trees with light or moderate damage.

Table 1. *Crown damage effects on seasonal mean sap volume, daily air temperature range (Ta range), tap hole closure, and fall root starch content in sugar maple trees in eastern Ontario. Means followed by the same letter are not significantly different ($p \leq 0.05$).*

Damage level	2004 sap volume per tap (Litres)	2004 fall tap hole closure (% closed)	2003 fall root starch content (%)	2004 daily Ta range (°C)
Light	42.6 a	39.4 a	1.67 a	10.7 b
Moderate	42.1 a	39.0 a	1.90 a	11.6 a
Severe	47.2 a	36.0 a	1.77 a	11.6 ab

Table 2. *Mean tree height, diameter at breast height (DBH), and number of tertiary branches per tree for sugar maple trees in eastern Ontario. Means followed by the same letter are not significantly different ($p \leq 0.05$)*

Damage level	Tree height (m)	DBH (cm)	Branch No.
Light	22.6 a	39.1 a	18.6 a
Moderate	23.2 a	44.5 a	18.7 a
Severe	21.4 b	43.9 a	12.3 b

Maximum and minimum daily temperatures swings were greater in moderately and severely damaged blocks (Table 1). However, the nearly 1°C difference was only significant in the moderately damaged blocks. (In 2 of the severely damaged blocks the temperature sensors failed soon after installation.)

Dolomitic lime and fertilizer treatments did not significantly affect diameter growth, sap volume production, sap sugar content, syrup production, or tap hole closure (data not shown).

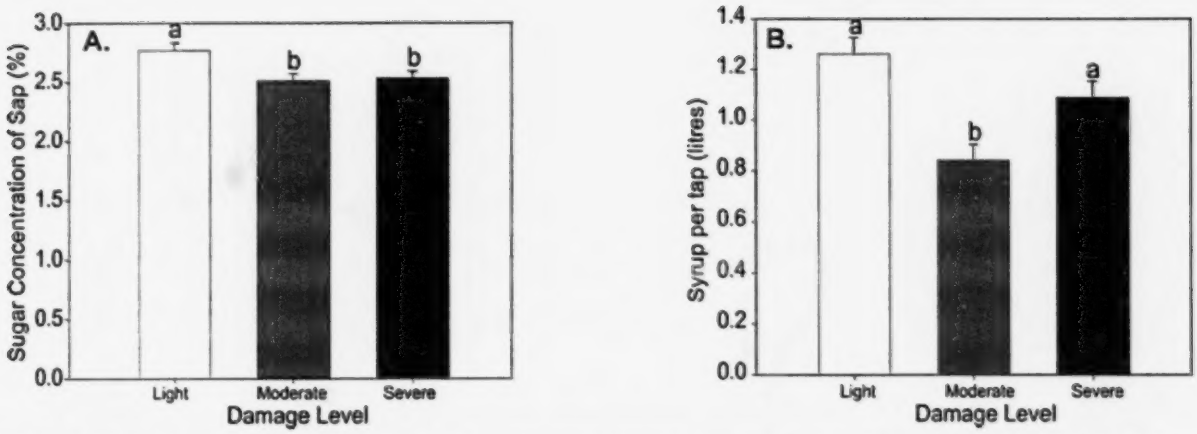

Figure 1. *Effect of ice storm damage on: A. 2004 (year 6 post ice storm) seasonal sugar content of sap (Mean + Std. Err.) and B. Calculated 2004 seasonal syrup production per tap (Mean + Std. Err.) in sugar maple trees from 15 tapped stands in eastern Ontario. Vertical bars topped by the same letters are not significantly different (p≤0.05).*

Discussion

The crown of a sugar maple tree can be viewed as its photosynthetic factory for producing sugar, which is used for new tissue growth and maintenance of existing tissues. By removing a significant portion of this crown, the ice storm of 1998 reduced the capacity of the tree to produce energy (sugar) needed for maintenance of existing tissues (respiration), growth, and development. Storm damage was assessed as the percentage of live crown removed. Although damage provides a rough assessment of the ice storm impact on the tree's ability to produce energy, it does not account for differences in initial crown size and the differing ability with age (Kramer and Kozlowski 1979) and crown classification (Meating et al. 2000) to replace lost branches by forming new epicormic branches. Therefore, the impact of 50% damage on a tree that initially had 50 tertiary branches may not have been as great as on a second tree that had 20 such branches before the storm. In addition, tree age and its condition prior to the storm (Proulx and Greene 2001) will influence the degree to which it will be affected by ice storm damage. All of these factors have been considered when interpreting the results because they likely influenced the response of the trees to the ice storm damage and were therefore a significant source of stand to stand variability in response.

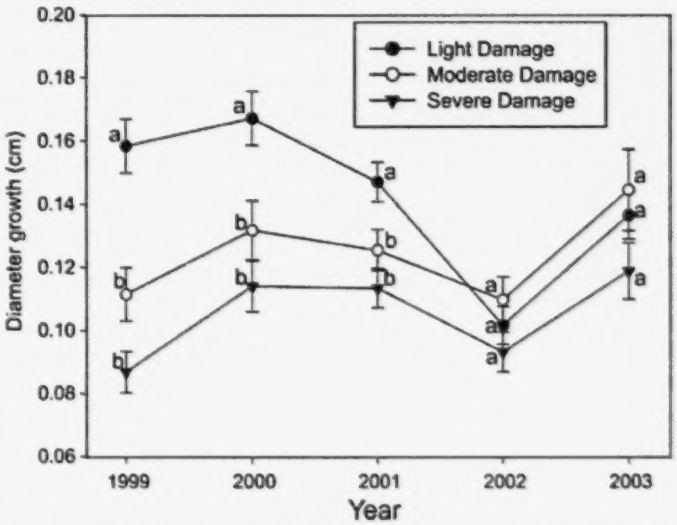

Figure 2. *Effect of ice storm damage on mean diameter growth (± Std. Err.) in sugar maple trees from 15 tapped stands in eastern Ontario. Within each year means marked by the same letter are not significantly different (P ≤ 0.05).*

The trees in the 3 crown damage classes had similar mean diameters and heights varied only 1 to 1.5 m (Table 2). Number of branches were reduced by about 33% in the trees classified as severely damaged compared to lightly and moderately damaged trees. Since branches were counted after the storm, this reduction was probably, at least in part, due to the higher damage levels in severely damaged trees. These results suggest that the trees in the 3 damage classes sampled for this study were of a comparable size and age, and probably did not have significant differences in susceptibility to damage because of these factors.

Root starch was not affected by crown damage level by the fall of 2003, the sixth year after the ice storm. In contrast, severe crown damage (>50 %) lowered fall root starch concentration in 2 of the first 3 years it was measured (Noland 2003). Reductions

in autumn root starch levels have also been reported for 2 consecutive years in sugar maple trees where crown dieback due to decline equalled or exceeded 50% (Renaud and Mauffette 1991). Death of sugar maple trees has been associated with shoot and root starch depletion in artificially defoliated trees (Gregory and Wargo 1986). Severe insect defoliation (>90%) also reduced fall root starch levels in sugar maple for 2 successive years (Kolb et al. 1992). The longer-term effects of defoliation or crown damage on root starch have not been reported elsewhere. Our results suggest that 6 years after the crown damage occurred, trees with moderate and severe crown damage have recovered sufficiently to maintain root starch levels similar to trees that sustained light damage.

Diameter growth was affected by ice storm damage. Growth was reduced through 2001 in moderately and severely damaged trees, but trees appeared to rebound in 2002 and 2003. This agrees with the prediction by Lautenschlager et al. (2003) that growth in moderately damaged trees would recover in 4 years, but contradicts their contention that 8 years would be required for the severely damaged trees to do the same.

Daily air temperature extremes in moderately damaged blocks were about 1°C greater than in lightly damaged stands. Although a similar difference was apparent in severely damaged stands, it lacked statistical significance probably due, at least in part, to the loss of temperature data from 2 blocks because of temperature sensor failure. Similar damage-related diurnal temperature trends in most of the same blocks were previously reported (Parker 2003). Although these temperature differences are small, they could be an important factor in sap volume production that is driven by the temperature extremes above and below freezing during the sap run (Kim and Leech 1985).

Ice storm damage reduced sap sweetness and syrup production, but results varied with damage level. Sap sugar content was significantly lowered by moderate and severe crown damage, but syrup production was lower only in moderately damaged trees. In a review of ice storm effects on maple, Coons (1999) was unable to find literature documenting the effect of ice storms on sugar maple sap and syrup production. The ice storm of 1998, with its significant impact to the maple syrup industry in North America (Irland 1998), provided the impetus for this study in Ontario and that of Campbell *et al.* (2001) in New York state which, to our knowledge, are the first reports that ice storm-induced damage to sugar maple crowns reduces sap volume and sweetness and syrup production (Noland 2003) for up to 6 years (7 sap runs) after the damage event.

Lime and fertilizer treatments did not significantly affect sap volume, sap sweetness, syrup production, tap hole closure, or diameter growth of trees in the 15 tapped blocks used for this study. Using the entire 34 blocks of the ice storm plot network, the P and K treatments were found to enhance the recovery of sugar maple from crown damage by stimulating diameter growth (Lautenschlager et al. 2003, Timmer et al. 2003). Fertilizer treatments have been found to both slightly increase sap volume production and slightly lower sap sugar content in moderately stressed maple trees with the effect dependent upon the specific fertilizer mix used (Barry and Roy 1998). Another study reported increases of about 15% in sugar production in healthy sugar maple trees fertilized with K, Ca, and Mg compared to unfertilized trees (Wilmot and Perkins 2004). It is possible that fertilizer treatments could be used in the future to speed recovery of trees from crown damage, but fertilizer effects on recovery of syrup production capacity are uncertain. On the other hand, since sugar maple growth response to liming treatments is reported to be a long-term process requiring up to 7 years for significant growth effects (Long et al. 1997), it may be too early to detect the effects of liming treatment in our study.

In conclusion, ice storm-damaged sugar maple trees tended to produce sap with lower sugar concentrations and therefore reduce syrup production. The ice storm damage has proven to be significant for the longer-term since its effects have persisted for 7 sap runs (6 years). This suggests that as further stresses such as drought, heat, or additional crown damage are experienced by the moderate or severely damaged trees in the future, productivity and health of these trees will continue to be compromised.

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